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# Low Cost Hydrogen Production Platform

Cooperative Agreement: DE-FC36-01GO11004

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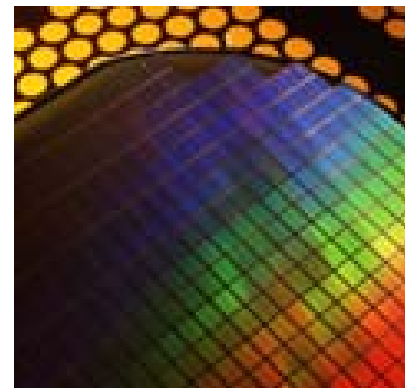
Timothy M. Aaron

## Team

Praxair - Tonawanda, NY

Boothroyd-Dewhurst - Wakefield, RI

Diversified Manufacturing - Lockport, NY



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**DOE Hydrogen Annual Review Meeting**  
**May 24 - 27, 2004**

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# **Objectives - LCHPP Program**



- **Low Cost On-Site Production of Hydrogen**
  - Existing Technologies (SMR)
  - Transportation & Industrial (1,000 - 5,000 scfh) (2.4 - 12 kg/h)
- **Year in Review**
  - Completed Phase I - 05/03
    - Preliminary Design
    - Economic Models & Business Cases
  - Started Phase II - 10/03
    - Detail Design & Engineering of System
    - Computer Simulations & Modeling
    - System Optimization
    - Component Testing
    - Update of Cost Models

# ***Budget - LCHPP Program***



- **Phase I (10/01 - 04/03) - Completed**
  - Total Cost: \$341,848
  - Cost Share: 67% - DOE, 33% - Praxair
  - FY2003 Funds (10/02 - 09/03) - \$220,643
- **Phase II (10/03 - 05/05) - In Progress**
  - Estimated Cost: \$1,989,933
  - Cost Share: 50/50 - DOE/Praxair
  - FY2003 Funds (10/02 - 09/03) - \$0
  - FY2004 Estimated Funds (10/03 - 09/04) - \$975,000
- **Phase III (06/05 - 12/06)**
  - TBD

# **Technical Barriers & Targets**



## ➤ **DOE Technical Barriers**

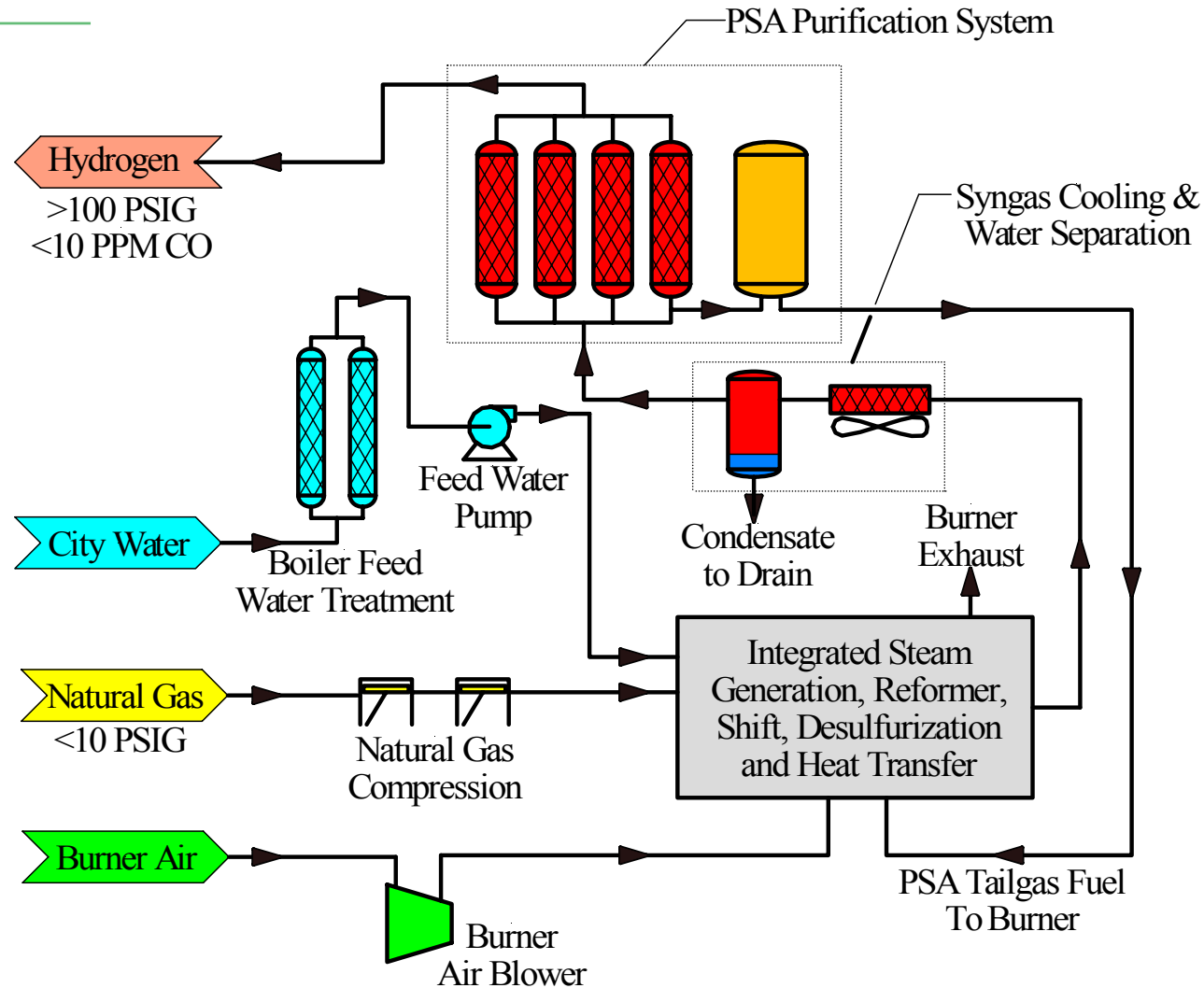
- A. Fuel Processor Capital Costs
- B. Operation and Maintenance (O&M) Costs
- C. Feedstock and Water Issues
- E. Control and Safety
- Z. Catalysts
- AB. Hydrogen Separation and Purification

## ➤ **DOE Technical Targets (w/o Comp, Storage & Dispensing)**

- |   |                                    |
|---|------------------------------------|
| ● <b>Cost Targets (\$/kg H<sub>2</sub>)</b> | ● <b>Primary Energy Efficiency</b> |
| ■ 2003 - 4.34                               | ■ 2003 - 62%                       |
| ■ 2005 - 2.44                               | ■ 2005 - 68%                       |
| ■ 2010 - 1.06                               | ■ 2010 - 75%                       |

- **Develop Small SMR Based Hydrogen System**
  - Phase I (Completed)
    - Preliminary Design & Techno-Economic Study
  - Phase II (10/03 - 05/05)
    - Detail Design & Optimization
      - ◆ Increase System Efficiency
      - ◆ Lower Capital Cost
      - ◆ Comply/Develop Safety & Design Standards
    - Component Modeling & Testing
    - Catalyst Analysis
    - Economic Model Updates
  - Phase III (06/05 - 12/06)
    - Prototype System

# LCHPP - Skid Process Flow



# High Temperature Component



## ➤ Functions

- Natural Gas Pre-Heat
- Desulfurization
- Reforming
- Water-Gas Shift Reactor
- Steam Generation & Superheat
- Combustion
- Air/Exhaust/Process Heat Exchange
- Syngas Cooling

## ➤ Design

- DFMA
- Highly Integrated
- Welded Construction

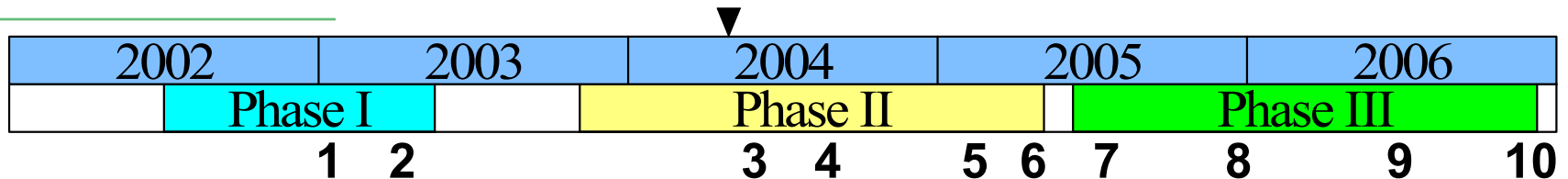


## ➤ Design Safety

- Risk Analysis Completed in Phase I
- Full HAZOP Review of System Will be Performed
- All Applicable Standards Will Be Followed
  - NEC
  - NFPA
  - ISO
  - Praxair Design Standards & Procedures
- Member of ISO Technical Committee 197 - WG 9
  - ISO 16110-1 & 2: Hydrogen generators using fuel processing technologies
    - ◆ Part 1: Safety
    - ◆ Part 2: Performance



# Project Timeline



## ➤ Phase I - Preliminary Design

1. Preliminary Component & System Design
2. Techno-Economic Study

## ➤ Phase II - Detail Design & Optimization

3. Detail Design & Computer Models
4. Construct Test Apparatus
5. Component Testing
6. Update System Design and Economic Models

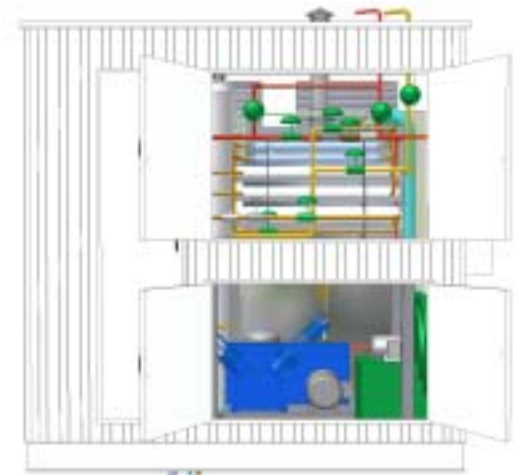
## ➤ Phase III - Prototype System

7. Complete Prototype Design
8. Build Prototype System
9. Verify System Performance & Update Economics
10. Commercialize System

# Phase I Review - System Design



- Safety
- Compact, Single Skid
- Easily Installed
- Welded Construction
- Highly Integrated



# ***Technical Progress (04/03 - 04/04)***



## ➤ **Phase I Completed**

- Preferred Design Chosen
- Report & Phase II Proposal

## ➤ **Phase II (Started 10/03)**

- Detail Design of System
  - Process & Instrumentation Diagram
  - Process Computer Simulations
  - Startup, Operating & Shutdown
  - Material Selection & Mechanical Stress Models
  - Component Modeling & Testing
  - Component Test Plan
  - Design of Test Apparatus
  - Catalyst Modeling & Testing

# ***Technical Accomplishments***



## ➤ **Design**

- Completed Detail Design of High Temp Component
  - Drawings
  - Process Models
- Optimized System
  - Reduced Mass of System
  - Reduced Parts & Assembly Complexity
  - Increased Thermal Efficiency
    - ◆ Increased Primary Energy Efficiency
    - ◆ Reduced Product Cost

# ***LCHPP - System Cost Model Parameters***



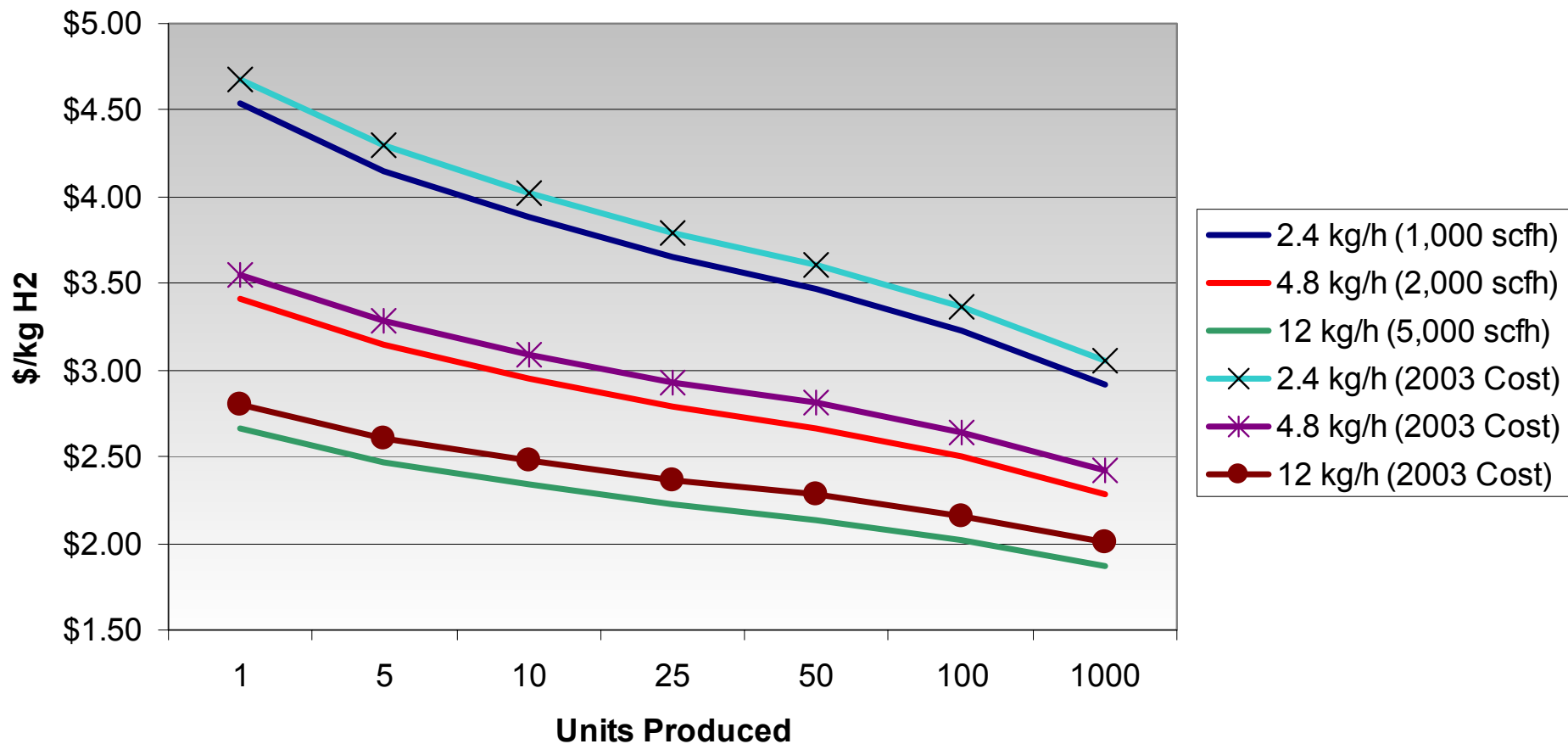
## **➤ Cost Model Assumptions**

- Power - \$0.05 \$/kWh
- Natural Gas - \$4.00 \$/MMBtu, HHV
- Water - \$2.50 per 1,000 Gallon
- Capital Recovery Factor - 15% Return, 15 Yr Life
- On-Stream Factor - 80%
- Contingency - 10%
- M&R - 3% of Capital
- Site Labor
  - 15% @ 1 Unit ==> 2% @ 1000 Units

# Technical Accomplishments / Cost of Hydrogen



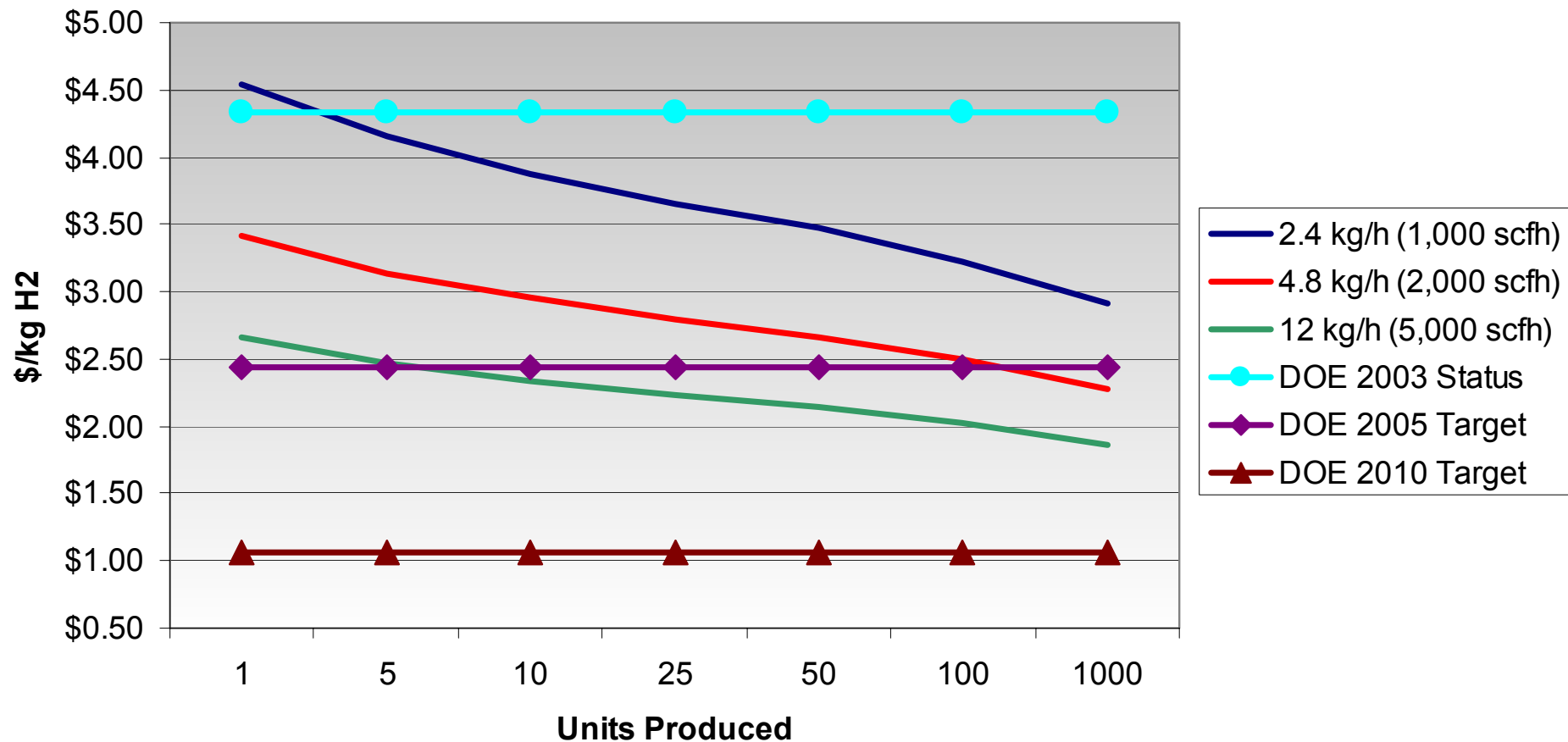
## H2 Cost vs Units Produced and H2 Flowrate



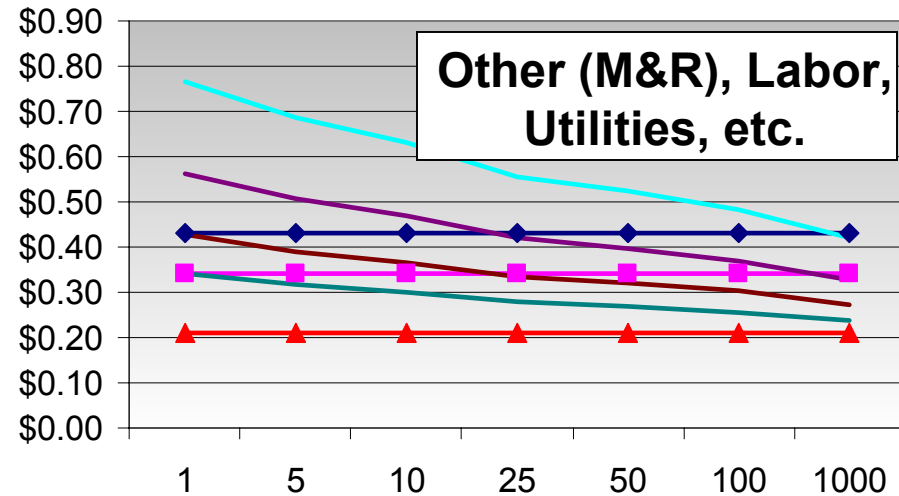
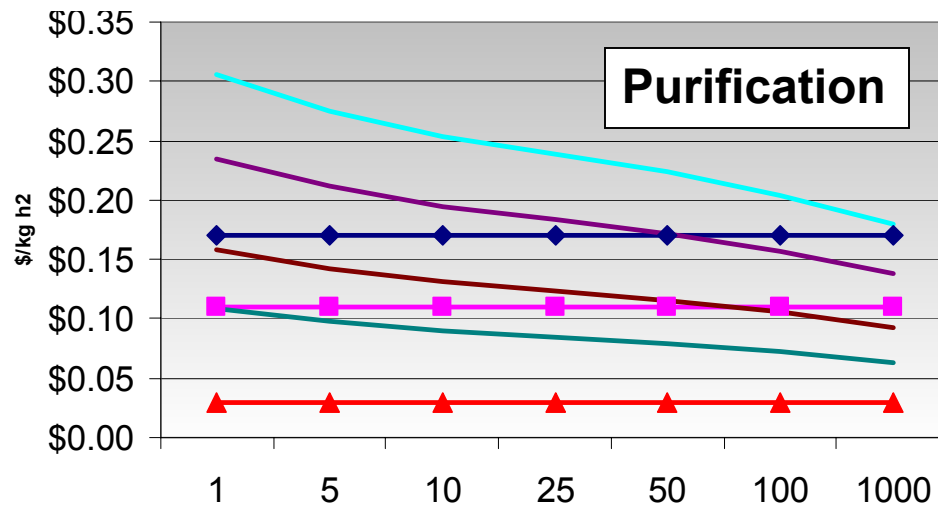
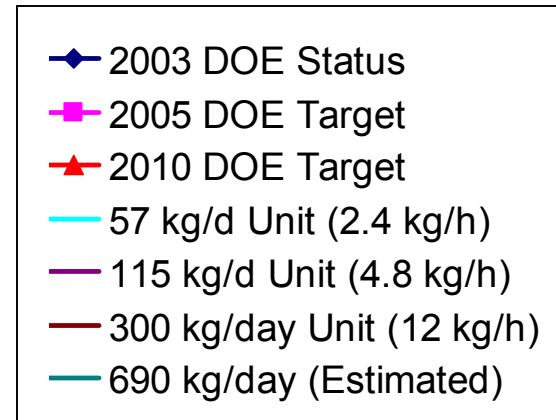
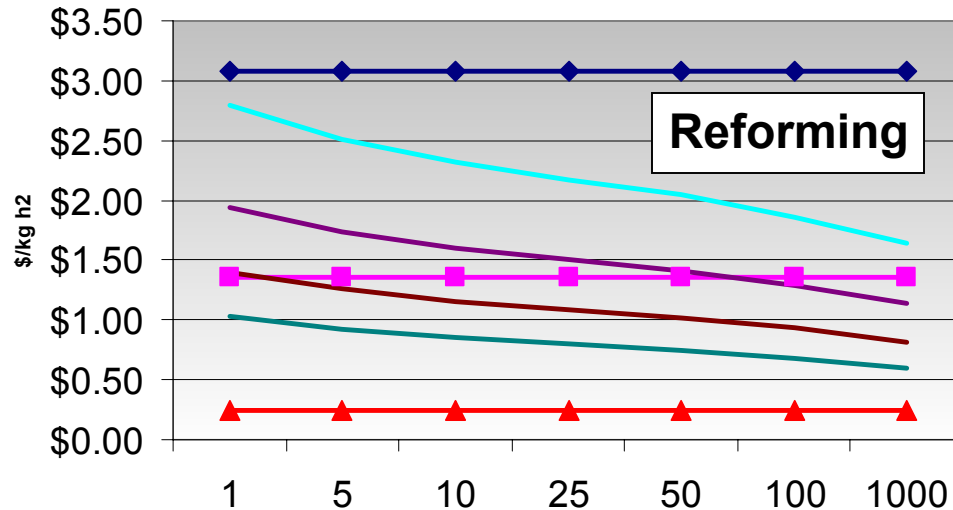
# Technical Accomplishments / DOE Program Goals



## H2 Cost vs Units Produced and H2 Flowrate



# Technical Accomplishments / DOE Program Goals (H<sub>2</sub> Cost vs. Units Produced)





# ***LCHPP - Future Work***



- **Verification of Results to Date**
  - Modeling & Simulations
    - Heat Transfer
    - Fluid Dynamics
    - Reaction Kinetics
    - Burner Design
  - Testing
    - Components
    - Catalysts
    - Water Treatment
    - Etc.
  - Maintain / Reduce Cost of Product
    - DFMA Techniques
    - Material Selection
    - Process Optimization

# Phase II Cooperative Efforts



## ➤ Praxair

- Overall Lead



## ➤ Boothroyd-Dewhurst

- System Optimization
- Cost Reduction / Estimating



## ➤ Diversified Manufacturing

- Manufacturing
- Prototype Development



## ➤ Computer Modeling

- Reformer / Shift Design
- Burner Design
- Heat Transfer

## ➤ Catalyst Supplier

# ***LCHPP - Interactions & Collaborations***



- **Society of Automotive Engineers (SAE)**
  - Paper & Presentation (October 2003)
    - DFMA Approach to Reducing the Cost of Hydrogen Produced from Natural Gas
- **The 2003 Hydrogen Production & Storage Forum (Washington, D.C.)**
  - Presentation & Roundtable Discussion (December 2003)
    - Using DFMA to Reduce the Cost of Hydrogen from Small Steam Methane Reformer Based Systems
- **ISO Technical Committee 197 - WG 9 (Member)**
  - ISO 16110-1 & 2: Hydrogen generators using fuel processing technologies

# 2003 Reviewers' Comments



- **Project would benefit if Compression, Storage & Dispensing Included in Scope of design**
  - Praxair/DOE Projects With This Scope
    - GEERC
    - LAX Fueling Station
    - These Projects are being monitored & assessed for Integration potential
- **Does not address Codes & Standards Issues**
  - Member of ISO committee related to applicable Standard
  - Praxair has Representation on many Standards Committees related to hydrogen production & plant citing
- **Techno-Economic Study should be done only after system concept has been proved**
  - Economic model is relatively easy and cost effective to develop and results in an understanding of the system potential. Proof of concept requires a test program and significant resources that would not be expended if economics did not warrant the development effort.

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## Questions?

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